LIGHTING IN ITS RELATION TO THE EYE.

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(*Read April 13, 1917.*)

I. Introduction.

The work of which this paper is a brief outline was done under the auspices of the American Medical Association's subcommittee on the hygiene of the eye, of which Dr. William Cambell Posey, of Philadelphia, is chairman, and has been in progress for six years. The object of the work has been to compare the effect of different lighting conditions on the eye, and to find the factors in a lighting situation which cause the eye to lose in efficiency and to experience discomfort. In all 52 different lighting situations have been investigated, selected with special reference to the problem in hand. Also a number of miscellaneous experiments have been conducted pertaining to the hygienic employment of the eye.

Confronting the problem of the effect of different lighting conditions on the eye, it is obvious that the first step towards systematic work is to obtain some means of estimating effect. The prominent effects of bad lighting systems are loss of efficiency, temporary and progressive, and eye discomfort. Three classes of effect, however, may be investigated: (1) The effect on the general level or scale of efficiency of the fresh eye; (2) loss of efficiency as the result of a period of work; and (3) the tendency to produce discomfort. A description of tests designed especially for this work has previously appeared in print. Some of these tests have been designed to determine the eye's aggregate loss in functional power, others to aid in the analysis of this effect. Time can be taken here only for the briefest mention of the principles on which they are based. The one with which the greater part of the work has been done is a test for determining the power of the eye to sustain clear seeing. Just two principles are involved in this test. One is that visual acuity or clearness of seeing may be measured by the smallest visual angle

which the eye is able to discriminate; the other, a principle equally old, is that a loss of efficiency in a machine, apparatus, or a living organ or organism will show out more plainly when a prolonged rather than a momentary performance is required. These principles in their simplest terms have been combined into a test of the comparative ability of the eye to maintain its power of clear seeing or aggregate functional activity under different conditions of lighting and under different kinds and conditions of use. Such a test for clear seeing was needed because the conventional acuity test had not been found to be sufficiently sensitive to fatigue conditions to warrant adoption in our work. It, we scarcely need to point out, was designed to test the dioptric condition of the eye and may be used with more or less success as a test of how far a given lighting condition is conducive to clear seeing with a maximum of momentary effort; but it has not the essentials of a fatigue test, nor of its converse, the ease with which clearness of seeing is maintained, which are the features needed primarily for the selection of lighting conditions for the greater part of the work that we are ordinarily called upon to do. Almost, if not quite, as good results, for example, may be gotten with it after work as before when there is every other reason to believe that the eye has suffered considerable depression in functional power. The reason for this is obvious. Although greatly fatigued, the eye can under the spur of the test be whipped up to give almost if not quite as good results as the non-fatigued organ when only a momentary effort is required. If fatigued, however, it can not be expected to maintain this extra effort for a period of time. The demonstration of this fact led early in our work to the introduction of a time element into the test. The principle involved is not a new one. It is merely the application of a very old and well-known one to the work of testing for ocular fatigue. If, for example, a sensitive test is wanted for the detection of fatigue in a muscle, as good results can not be expected if the test requires only a momentary effort on the part of the muscle as would be attained if the endurance of the muscle were taken into account. For our purpose, therefore, the old acuity test subjected to certain features of standardization for the sake of greater reproducibility has been made into an endurance test in which the fatigue or loss of func-

tional efficiency of the eye is measured by its power to sustain clear seeing for a period of time. In operation the test may be described briefly as follows: The power of the eye to sustain a certain standard of acuity for three minutes is measured before and after a 3-hour period of reading from uniform type and paper under the lighting conditions to be tested. That is, by means of a visual acuity test object, with the proper auxiliary apparatus for its control and observation, and a kymograph and chronograph, records are made of the time the eye can be held up to this standard of performance and the time it drops below. The ratio of these quantities to each other, or to the total time for which the record is made, is taken as the measure of the ability of the eye to sustain its power of clear seeing before and after work under the lighting conditions to be tested.

Thus far the analytical tests have been confined to the retina and the extrinsic muscles of the eye. There are four ways in which the retina might be expected to show a depression of functional power: in a lowering of sensitivity to colored and white light; in an increase in the rate of exhaustion to light stimulation and a corresponding decrease in rate of recovery; and in an increase in the lag or time required to give its full response to light stimulation. We have already made tests for the first three of these features for the effect of different lighting conditions and work is under way for the testing of the fourth feature. In the work on the extrinsic muscles we have again found it advisable for the sake of sensitivity in detecting small effects to use an endurance test instead of one requiring only a momentary performance. That is, we have supplemented the conventional abduction and adduction tests by a determination of the power to sustain the coördination of action on the part of these muscles needed for binocular seeing—measured by the power to maintain under strain the accurate combination of binocular images of a simple test-object before and after a period of work under the lighting conditions to be tested. The eyes are put under strain to combine their images to give the needed sensitivity to the test. When this is done even when the muscles are fresh, if the object is looked at or fixated for an interval of time, it will be seen alternately as one or as two. The proportion or ratio of the time seen as one to the time seen as two or to the total time of the observation can

be regulated by the amount of initial strain under which the eyes are put to combine their images. The regulation of this ratio is empirical and of importance; for, as is the case with the test for loss of efficiency for clear seeing, the sensitivity of the test depends to a considerable extent upon the initial value that is given to this ratio. The eyes may be put under strain to combine their images by interposing between them and the object viewed weak prisms and by adjusting them and regulating the distance of the object from the eye so that with the maximum of effort to see it as one, it is seen alternately as one or as two in the proportion desired.

We have also tested the tendency of different conditions of lighting to produce ocular discomfort, and have explored the field of vision for the purpose of determining the liability to discomfort from the exposure of the eye to surface brilliancies of different orders of magnitude. This tendency was measured by the time required for just noticeable discomfort to be set up, in the former case both with the eye at work and at rest under the lighting conditions in question, and in the latter with the eye systematically exposed to a given area and brilliancy of surface at different points in the visual field, by means of a large perimeter constructed especially for the purpose.

The following aspects of lighting sustain an important relation to the eye: the evenness of illumination, the diffuseness of light, the angle at which the light falls on the object viewed, the evenness of surface brightness, the intensity of light, and its composition or color value. For convenience of treatment in this paper we have grouped the first four of these under the heading distribution factors. The work throughout has been conducted primarily for the purpose of finding out the comparative importance of these factors to the comfortable and efficient use of the eye rather than to test the merits of various types and varieties of lighting. On the other hand, however, the investigations have not been abstract in character. That is, all the variations obtained were gotten in actual lighting situations by employing so far as possible lighting installations in common use. In order that a correlation might be had between lighting conditions and effect on the eye, the following specifications of illumination effects and conditions was made in each case.

1. A determination was made of the average illumination of the test room under each of the installations of lighting used, and of the distribution of light in the room. The room was laid out in 3 ft. squares and measurements were made of the horizontal, vertical and 45° components of illumination at 66 of the intersections of the sides of these squares, and at the point of work. In all cases in which the variation of intensity was not the special point of investigation, the illumination for each installation was made as nearly equal as possible at the point of work.

2. A determination was made in candlepower per square inch of the brightness of prominent objects in the room, such as the test surface and reading page; the ceiling spots above the reflectors for the indirect installations; the reflectors and the ceiling spots above the reflectors for the semi-indirect installations; the reflectors, openings of reflectors and the lamps in so far as they were visible for the direct installations; the specular reflections from surfaces, etc.; and the surfaces of lowest brightness to get the range.

3. Since the angle of presentation is an important feature in the effect on the eye, a determination was made also of the angle of elevation of some of the more important surfaces such as the reflector, opening of the reflector, etc., above the plane of the observer's eye when held in the working position.

4. Photographs were taken of the room from three positions under each system of illumination.

In the selection and use of observers for the work the following are some of the precautions that were taken: Care was exercised in the first place to choose only those who had shown already a satisfactory degree of precision in other work in physiological optics and whose clinic record showed no uncorrected defects of consequence. All were under 30 years of age. Before being allowed to take part in the actual work of testing each observer was trained to a satisfactory degree of precision in the 3-minute record under a given lighting condition and in the 3-hour test under several of the conditions to be tested. In the actual work of testing the results were compiled from several observations and the precision was checked up by the size of the mean error. No results were accepted as significant unless the variation produced by changing the conditions to be

tested was largely in excess of the mean variation or mean error for each condition tested. This, the accepted conventional check on the influence of variable extraneous factors was carefully applied at each step in the work.

In attempting to make any presentation of results for a problem so complicated as the one under investigation, in the space allotted, we have had to choose between giving the details for some particular piece of work and trying to draw some general conclusions from the work as a whole, supplemented by an incomplete statement of data,[1] so far as the tests have been applied up to the present time. We have chosen the latter alternative, although caution and our own preference are on the side of the former.

As already stated, the work has been in progress for six years.

[1] For a detailed statement of the data obtained in these experiments the reader is referred to the *Transactions of the Illuminating Engineering Society*, 1913, VIII., pp. 40–60; 1915, X., pp. 407–447; 448–501; 1097–1138; 1916, XI., pp. 1111–1137; 1917, XII., pp. 464–487.

In these references will be found data on the following points for the lighting conditions tested: (*a*) The horizontal, 45° and vertical components of illumination at the 66 stations in the test room, the mean deviation of these values from the average illumination and the percentage mean deviation in some of the more important cases. (*b*) Measurements in candlepower per square inch of the brightness of prominent objects in the room, such as the test surface, the reading page, the ceiling spots above the reflectors for the indirect installations; the reflectors and the ceiling spots above the reflectors for the semi-indirect installations; the specular reflections from surfaces; etc.; and the surfaces of lowest brightness to get the range. (*c*) Ratios between surfaces of the first, second, third, etc., order of brilliancy and surfaces of the lowest order of brilliancy, and between surfaces of the first, second and third order of brilliancy and the brightness at the point of work, to show the gradations in surface brightness. Again in some of the more important cases the mean deviation of the brightness values of the different surfaces from the average brightness of all the surfaces measured, and the percentage mean deviation have been given. (*d*) The angle of elevation of some of the more important surfaces such as the reflector, opening of the reflector, etc., above the plane of the observer's eye when in the working position. (*e*) Photographs for each system of illumination representing to the eye the details of the test room, the location and type of lighting units, the position of the test station, the apparatus with which the tests were made, the illumination effects (distribution of light and surface brightness), etc. And (*f*) tables giving a detailed numerical statement of the results of the test including among other items a comparison of the average error of each set of determinations with the change of result produced by changing the lighting conditions tested, as a check on the significance of the results.

We have avoided, therefore, as far as possible, making any comparison of results in different series or years; but wherever this has been done, the comparisons are based on the results of the same observer with sufficient check experiments to show that the error of observation is safely within the variation in result upon which the conclusion is based. The following are some of the results that have been obtained.

1. Of the lighting factors that influence the welfare of the eye, those we have grouped under the heading distribution are apparently fundamental. Thus far in the work they seem to be the most important we have yet to deal with in our search for the conditions that give us the minimum loss of efficiency and the maximum comfort in seeing. If, for example, the light is well distributed in the field of vision and diffuse and there are no extremes of surface brightness, our tests indicate that the eye, so far as the problem of lighting is concerned, is practically independent of intensity of light. That is, when the proper distribution effects are obtained, intensities high enough to give the maximum discrimination of detail may be employed without causing appreciable fatigue or discomfort to the eye. The work on composition or color value of light is still in progress. While, therefore, we are not in a position to conclude fully on this point, our belief based on the work which has been done is that the color differences that are ordinarily present in artificial light are not nearly so important as are, for example, the differences in the precautions that are being used to exclude high brilliancies from the field of view. The defects with regard to color value are, however, as a practical problem harder to remedy.

2. For the type of control of distribution factors given by the semi-indirect reflectors of low and medium density and the direct reflectors which present, as many of them do, excessive brilliancies due to opening, surface of reflector, or wholly or partially exposed sources, our results show that often too much light is used in ordinary work for the comfort and welfare of the eye. That is, with these reflectors, means have not yet been found to produce this amount of light without introducing harmful brilliancies into the field of view.

3. The angle at which the light falls on the object viewed is an

important factor especially if the light is not well diffused and the surface of the object viewed is not sufficiently mat in character; but not so important, for example, as a certain evenness or gradation of surface brightness in the field of view. High brilliancies in the field of view seem in fact to be the most important cause of the eye's discomfort and loss in power to sustain clear seeing in lighting systems as we have them at the present time. In lighting from exposed sources it is not infrequent to find the brightest surface from one million to two and one half million times as brilliant as the darkest; and from three hundred thousand to six hundred thousand times as brilliant as the reading page. These extremes of brightness are, our tests show, very fatiguing to the eye, especially when the high brilliancies occur in certain zones or regions of the field of view.

4. Of the commercial systems of artificial lighting tested thus far, unmodified, the best results have been obtained for the indirect systems, and the semi-indirect systems with reflectors having a high density. By means of these reflectors the light is well distributed in the field of view and extremes of surface brilliancy are kept within the limits which the eyes are prepared to stand. A great deal of loss in power to sustain clear seeing has been found to result from the use of semi-indirect reflectors of low and medium density and from the use of direct reflectors of shallow and medium depth. With regard to the degree of density that is most favorable to the eye, the direct reflector seems, however, to present a special case. With translucent reflectors of medium depth, our best results have been gotten so far with reflectors of medium density. This, however, is not in contradiction to our principle that extremes of brightness are fatiguing to the eye. For if the physical efficiency of the reflector is not to be lowered by increasing its density, its opening must become brighter in some proportion to the increase of density; i. e., in a totally opaque reflector all, and in the denser reflectors nearly all of the light sent to the working plane must come from the opening. Moreover, in case of the denser reflectors, the ceiling and the reflectors are relatively dark, while standing out in sharp contrast to them is the bright opening of the reflector. In the reflectors of medium density, however, the reflector need not have such a high brilliancy and there is little contrast between it and its surroundings.

When installed on or near the ceiling in rooms of moderate height, the best results seem to be obtained when the opening, the surface of the reflector and the ceiling have as nearly as possible equal brilliancy. It seems probable that the effect on the eye of the denser reflectors can be very much improved by increasing the depth of the reflector and by other devices that will lower the brilliancy of the opening. In fact the best results we have as yet gotten from any type of reflector have been from a direct opaque reflector of the deep bowl type, modified so as greatly to reduce the brightness of the opening, giving a field of view with the lowest maximum of brilliancy of any we have as yet been able to obtain in an actual lighting situation. This reflector, 10¼ in. in diameter and 11½ in. deep, was lined to a depth of 3.7 in. with a mat surface having a reflection coefficient of about 4 per cent. Moreover, a result almost as good as any we have obtained by indirect lighting was gotten by giving this band or lining a reflection coefficient of about 38.5 per cent. In the former case the brightness of the opening taken from the position of the observer's eye was 0.0129 cp. per sq. in., a reduction of 99.8 per cent. in the maximum brilliancy of the opening; and in the latter, 0.1815 cp. per sq. in., a reduction of 96 per cent. In the former the illumination of the room was reduced on the average 25 per cent.; and in the latter, 12.4 per cent. Poor results are given by shallow direct reflectors of all densities unless they are installed so high above the working plane as to be almost if not entirely removed from the field of view.

5. We have frequently been asked to fix an upper limit of brightness which the eye can stand without any considerable loss in power to sustain clear seeing through a period of work. At present this can be done at best only very approximately; moreover, the value assigned can not be made independent of the grouping of conditions in which this brightness occurs. For example, a lighting installation which has its highest brightness well within the field of view demands a smaller maximum than one in which these brightnesses are carried outside the zone of most harmful effects on the eye. That is, higher brightnesses can be tolerated for the totally indirect reflectors, or for direct reflectors installed on the ceiling, than for semi-indirect reflectors in case of which the highest brightnesses,

namely, the brightnesses of the reflectors, are in rooms of moderate height dropped well into the field of view. It is obvious also that the effect will depend on the number and size of the bright surfaces in the field of view as well as on the angle of presentation to the eye. For rooms of the size of the one in which we worked, an approximation of a maximum brightness may be gotten from the following data based on the testing of 52 lighting situations. For the indirect installations the eye fell off 8.6 per cent. in power to meet the standard imposed by the test as the result of 3 hours of continuous reading with the maximum brightness in the field of view of 0.138 cp. per sq. in. For the direct installation the loss was 6.6 per cent. for a brightness of 0.0129 cp. per sq. in.; 8 per cent. for a brightness of 0.1815 cp. per sq. in.; and 32.9 per cent. for a brightness of 0.66 cp. per sq. in. For the semi-indirect installations the loss was 15 per cent. from a brightness of 0.264 cp. per sq. in.; 48 per cent. for a brightness of 0.361 cp. per sq. in.; and 60 per cent. for a brightness of 0.614 cp. per sq. in. We would not feel inclined to recommend a maximum brightness greater than 0.15–0.2 cp. per sq. in. with the grouping of distribution factors ordinarily found in the lighting of rooms. In contrast with this, the brightness of the gas flame and oil lamp is from 3–8 cp. per sq. in.; the Welsbach mantle from 20–50 cp. per sq. in.; the carbon filament from 375–480; the filament of the vacuum tungsten lamp from 875–1,000; the filament of the gas-filled tungsten lamp 10,271–16,433; and the open arc lamp from 10,000–50,000.

6. A marked characteristic of the effects produced by the dense and completely opaque direct reflectors was the low illumination of the ceiling and upper part of the room, and the high and in some cases almost glaring illumination of the floor and objects in the working plane. So far as the effects on the eye of the kind registered by our tests are concerned, however, these irregularities of illumination and of low surface brightness extraneous to the lamp and reflector seem to be of comparatively little consequence, so long as the higher brilliancies of lamp and reflector are themselves properly taken care of. With the direct reflectors, translucent and opaque, we have had quite wide variations in the distribution of illumination ranging from the well-illuminated ceilings and the com-

paratively evenly illuminated walls and working plane for the reflectors of medium density to the dark ceilings and upper part of the room and highly illumined lower half for the opaque reflectors. And with the opaque reflectors turned towards the ceiling, the translucent reflectors turned both up and down, and with reflectors of both the focusing and distributing types, we have had the greatest amount of light first in the upper half of the room, then in the lower half, and within limits lanes of light have been produced; still it has been possible to get in all of these cases comparatively good effects on the eye so long as no excessive brilliancies were introduced in the field of view. Again, however, we do not wish to say that this is the only factor that makes for the welfare of the eye. We wish only to call attention to its very great importance.

7. The problem of installing is not the same for the semi-indirect as for the totally indirect reflector. In the latter case the height should be adjusted so as to give as nearly as possible an even distribution of surface brightness on the ceiling and evenness of illumination on the working plane. In the case of the semi-indirect reflectors, especially those of low and medium densities and in rooms of medium height, if the distance from the ceiling is made great enough to produce these effects, the bright reflectors are dropped too low in the field of view for the highest comfort and efficiency of the eye. Apparently the denser they are, the more nearly they should be installed as are the indirect reflectors; and the less dense they are the more nearly they should be installed as are the direct reflectors of similar density, so far as eye effects of the kind revealed by our tests are concerned. In this connection it may be pointed out that in current practice direct reflectors for general illumination are usually installed on the ceiling or as near to it as is possible, especially in rooms of low and medium height. However, while this may be a good general rule for the installation of direct reflectors of low and medium density and of shallow and medium depth, the question of most favorable height for the dense and completely opaque reflectors is, we believe, still open to investigation.

8. In the work of providing general illumination the most difficult feature presented in the problem of protecting the eye is en-

countered in the lighting of rooms of low and medium height. The difficulty decreases with increase of the height of the ceiling. In rooms whose ceilings are very high in proportion to other dimensions of the room, it seems safe to say that comparatively good results could be gotten with almost any reflector of modern design; for it is much easier in such rooms to get the bright sources of light, primary and secondary, out of the zone of most harmful influence on the eye.

9. The loss of efficiency sustained by the eye in an unfavorable lighting situation seems to be muscular, not retinal. The retina has been found to lose little if any more in efficiency under one than under another of the lighting systems employed.

10. The observation of motion pictures for two or more hours causes the eye to lose heavily in efficiency. The loss decreases rather regularly with increase of distance from the projection screen. It seems little if any greater, however, than the loss caused by an equal period of steady reading under much of the artificial lighting now in actual use. In making these tests care was taken to choose a projection apparatus which gave a picture comparatively steady and free from flicker.

11. In all the conditions tested a rather close correlation is found to obtain between the tendency of a given lighting condition to cause loss of visual efficiency and to produce ocular discomfort. The tendency to produce ocular discomfort, as already stated, was estimated by the time required for just noticeable discomfort to be set up with the eye both working and at rest under the conditions to be tested. The results of this work were also carefully checked up by the determination of the mean error of the observation.

II. Some of the Conditions Tested (Commercial Types of Lighting).

The tests throughout the work were conducted in a room 30.5 ft. long, 22.2 ft. wide and 9.5 ft. high. In Fig. 1 this room is shown drawn to scale: north, south, east and west elevations, and plan of room. In the plan of room are shown by a cross and the appropriate numeral the 66 stations at which the illumination measure-

ments were made; also the positions of the outlets: *A, B, C, D, E, F, G* and *H* for the lighting fixtures. In the drawing east elevation, one of the positions at which the tests were taken is repre-

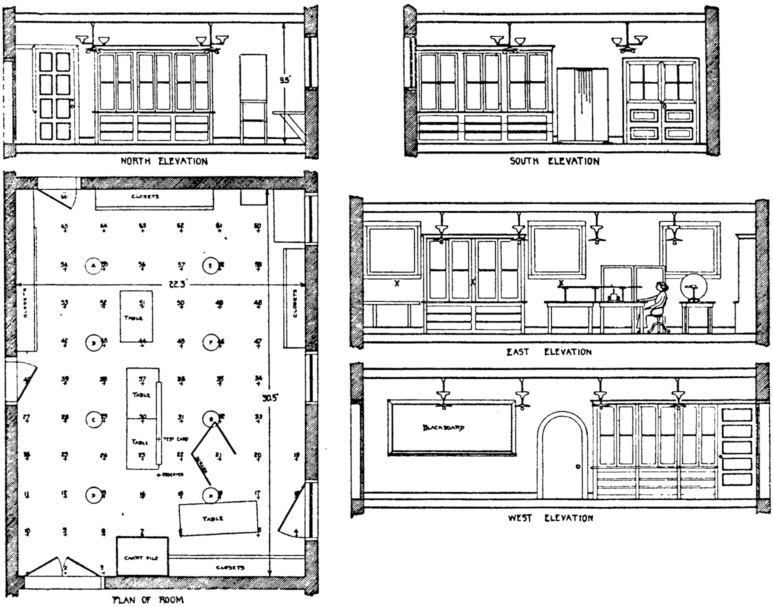

FIG. 1. Plan of test room.

sented, namely, the one with six reflectors in the field of view. The walls and ceilings of this room are of rough plaster painted a mat white. The floor is of medium dark tiling.

1. *Direct, Semi-indirect and Indirect Systems of Lighting.*

In our choice of the first set of conditions to be tested it was our purpose to make a selection that would give a wide variation in the distribution factors. Three types of lighting were chosen. One may be called an indirect system; one a direct system; and one a semi-indirect system. The direct reflectors were not of the most modern make, although they may be said to have given effects very similar to much of the lighting in actual use at the present time. They were of porcelain ware 16 inches in diameter and only slightly

concaved. When placed above the lamps employed, they served merely to direct the light to the working plane. No protection from the brilliancy of the light source was afforded to the eye. For the semi-indirect system inverted alba reflectors 11 inches in diameter

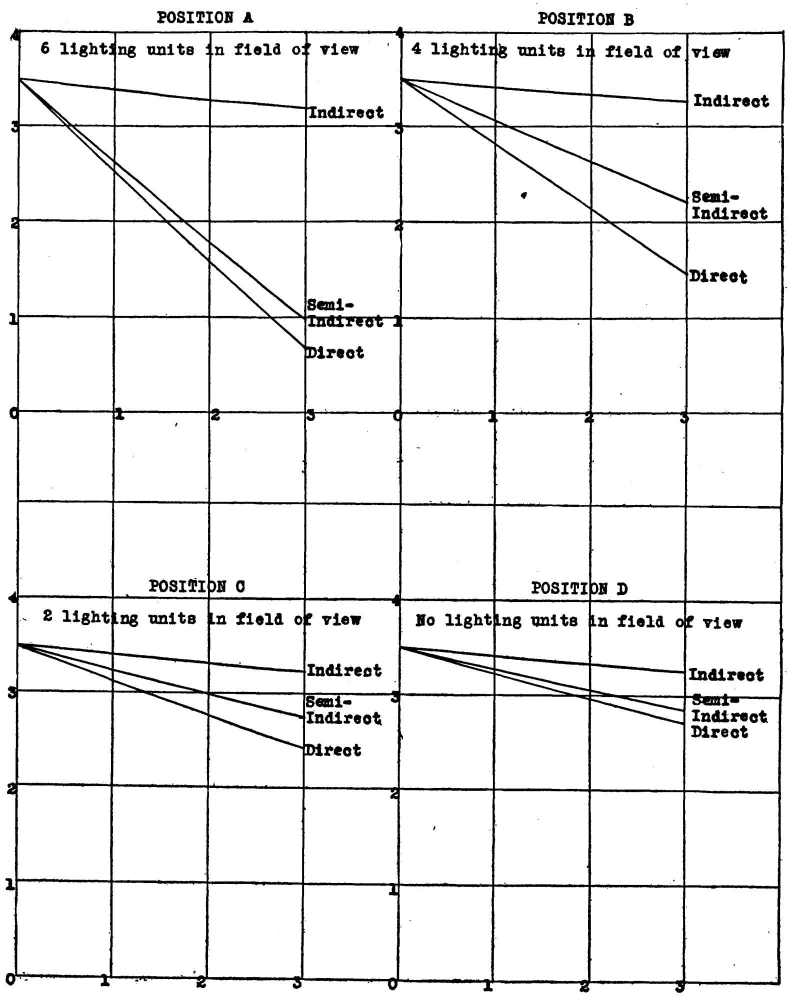

CHART I. (Direct, Semi-indirect and Indirect Systems of Lighting.) Showing the power of the eye to sustain clear seeing under direct, semi-indirect and indirect systems of lighting, and the effect of varying the observer's position in the room or the number of bright sources, primary and secondary, in the field of vision. Power to sustain clear seeing before and after work is represented on the ordinate and hours of work on the abscissa.

were employed. These reflectors are of modern design and represent very well glassware of medium density. In case of the indirect system corrugated mirror reflectors were used inclosed in brass bowls. These reflectors are also of modern design and give effects which may be taken to represent very well those obtained in good indirect lighting. The tests were taken at four positions in the room, one with six, one with four, one with two, and one with none of the lighting units in the field of view. The last three of these positions are marked with a cross in Fig. 1, east elevation. A graphic representation of the results of the tests for the four positions is given in Chart 1. Because of the amount of space that it would require, a tabular statement of results from which these and subsequent charts were constructed will not be given in this paper.

In the second series of experiments we undertook to determine the most favorable intensities of illumination for the three types of installations we had used in the first series; and in addition the effect of varying the intensity of the illumination with the particular grouping of distribution factors represented in each case. The tests were made in the same room, with the same fixtures, and in general with the same conditions of installation and methods of working as were described in the account of the experiments of the first series. To secure the various degrees of intensity of light needed, lamps of different wattages were employed. In order to keep the distribution factors as nearly constant as possible for a given type of system, the lamps used in making the tests for that type of system were all of one wattage, *i. e.*, were all 15's, 25's, 40's, 60's, or 100's. For the indirect and semi-indirect systems 25, 40, 60, and 100-watt lamps were employed. Our fixtures for the direct system were so installed that either one or two lamps could be used in each fixture, totalling respectively 8 and 16. In order to get a wider range of intensities both numbers of lamps were used, *i. e.*, one series of tests was made with 8 lamps, and another with 16. Also four intensities of light were employed in each case. These intensities were secured in the 8-lamp system by using lamps totalling 120, 365, 400 and 800 watts. In case of the semi-indirect and indirect reflectors socket extenders had to be used with the 25 and 40-watt lamps. That is, without the extenders these lamps,

on account of their smaller size, came so low in the reflectors as to change the distribution effects given by the reflector. For example, without the socket extenders with these shorter lamps, the spot of light on the ceiling, for the indirect system especially, was made smaller and correspondingly more brilliant. It was considered to be a point of interest in relation to the general problem to determine whether this comparatively small change in illumination effects would cause any difference in the eye's ability to hold its power to sustain clear seeing. The results of the tests for the different intensities of light for the three systems of lighting are shown in Chart II. Space need not be taken here to represent the comparative effects with and without socket extenders (see *Trans. Ill. Eng. Soc.*, 1915, X., pp. 473–476). In this connection it will be sufficient for our purpose here to state that quite an appreciable difference in result was obtained especially in case of the 25-watt lamps. These experiments constitute but one feature of a series conducted to show the effects of faulty installation.

2. *Semi-indirect Reflectors Differing in Density.*

In the work under the first and second sets of conditions the influence of differences in the distribution factors, more especially surface brightness, was clearly revealed by the use of wide variations in illumination effects. In the third set of conditions much smaller variations were employed. Such differences in effects were included as could be obtained by employing semi-indirect reflectors alone ranging from medium to dense. Six sets of reflectors were used, similar in size and shape and differing only in density. These reflectors were furnished by the Holophane Works of the General Electric Co. (now Ivanhoe-Regent Works) with special reference to the needs and purpose of the investigation. They are all of the bowl type and 8 inches in diameter. Reflector I. is a pressed Sudan toned brown; Reflector II. a blown white glass toned brown (an experimental product); Reflector III. a pressed Sudan; Reflector IV. a pressed Druid; Reflector V. a blown Veluria; and Reflector VI. a blown white glass (also an experimental product). Reflectors I., III., IV. and V. are commercial products, II. and VI. are in-

Lighting System: Semi-indirect.

	Watts.	Volts.	Foot Candles. Vertical.	Foot Candles. Horizontal.	Foot Candles. 45°.
A	200	107	1.60	0.45	1.15
B	200	110	1.72	0.484	1.29
C	320	107	2.20	0.58	1.52
D	320	110	2.31	0.62	1.61
E	480	107	3.30	0.94	2.40
F	800	107	6.80	1.82	4.50
X	760	107	5.80	1.45	4.0

Lighting System: Indirect.

	Watts.	Volts.	Foot Candles. Vertical.	Foot Candles. Horizontal.	Foot Candles. 45°.
A	200	107	1.33	0.39	0.87
B	320	107	1.7	0.49	1.08
C	480	107	3.0	0.765	1.97
D	800	107	5.2	1.36	3.50

Lighting System: Direct (8 Lamps).

	Watts.	Volts.	Foot Candles. Vertical.	Foot Candles. Horizontal.	Foot Candles. 45°.
A	120	107	0.64	0.32	0.49
B	200	107	1.16	0.45	0.85
C	320	107	1.97	0.65	1.39
D	480	107	2.60	1.02	2.0

Lighting System: Direct (16 Lamps).

	Watts.	Volts.	Foot Candles. Vertical.	Foot Candles. Horizontal.	Foot Candles. 45°.
A	240	107	1.23	0.54	0.935
B	365	107	1.60	0.60	1.33
C	400	107	1.86	0.80	1.46
X	880	107	4.20	1.41	2.60

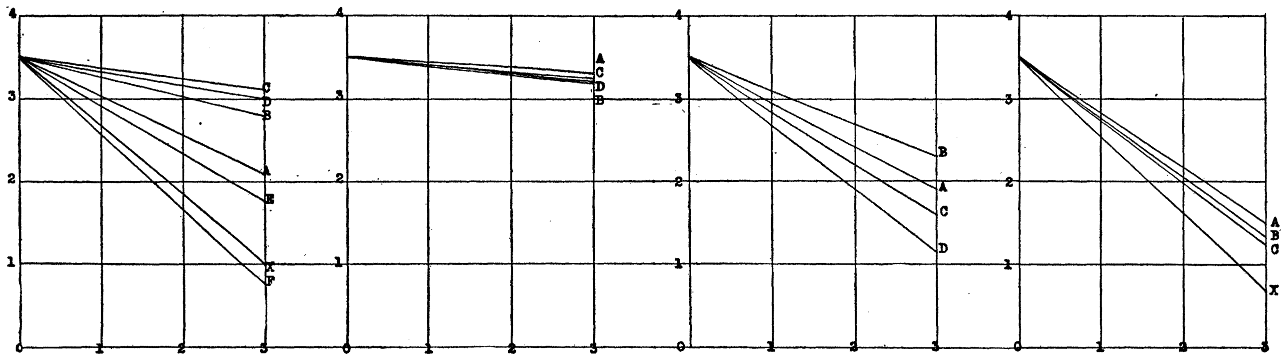

CHART II. (Direct, Semi-indirect and Indirect Systems of Lighting.) Showing the effect on power to sustain clear seeing of varying intensity of light for four installations of lighting: direct, semi-indirect and indirect systems, 8 lamps; and direct system, 16 lamps. Power to sustain clear seeing before and after work is represented on the ordinate and hours of work on the abscissa.

serted in the series to give gradations in density. These reflectors were installed 30 inches from the ceiling in accord with the principles of indirect lighting. Clear tungsten lamps were used as light sources with each installation. These reflectors are numbered in order of their density from greatest to least, that is, Reflector I. is

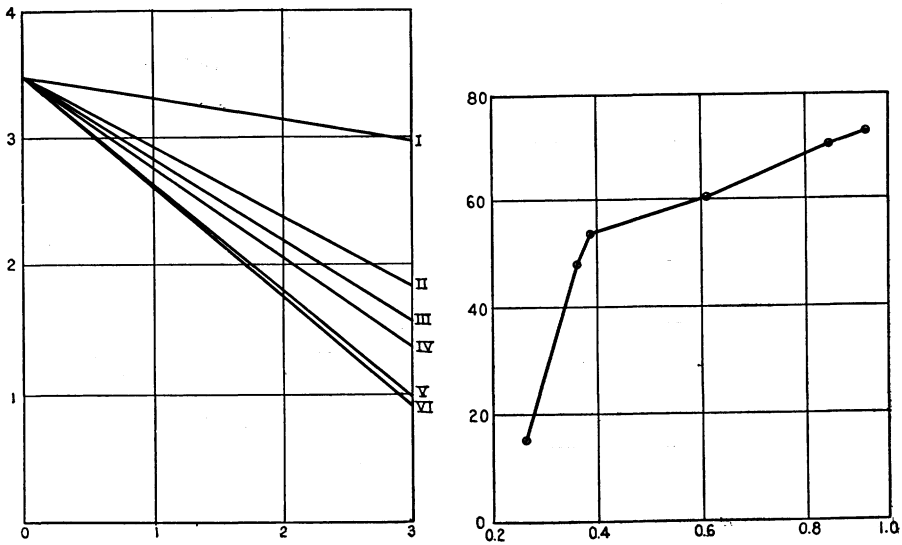

CHART III. (Semi-indirect Reflectors Differing in Density.) Showing the tendency of the six types of semi-indirect reflectors to cause loss of power to sustain clear seeing. In *A*, power to sustain clear seeing before and after work is represented on the ordinate and hours of work on the abscissa. In *B*, percentage of drop in power to sustain clear seeing after work for the different reflectors is plotted along the ordinate and brightness of reflector in candlepower per square inch along the abscissa.

Type of Reflector.	Volts.	Foot-candles.		45°.	Candle Power per Square Inch[5].
		Vertical.	Horizontal.		
I	111	4.1	1.14	2.7	0.264
II	110	3.7	1.13	2.6	0.361
III	107.5	4.2	1.16	2.6	0.392
IV	105.5	3.8	1.15	2.5	0.614
V	105.5	3.7	1.15	2.6	0.848
VI	107.5	4.2	1.16	2.7	0.920

[5] By multiplying the above values by 486.8 they may be converted into millilamberts, a term frequently used by engineers to specify small brightness quantities.

of the greatest and Reflector VI. is of the least density. In this connection it is scarcely needful to mention that the greater is the density of the reflector, the lower is the brilliancy of the surface which it presents to the eye. The results of this series of experiments are represented in Chart III.

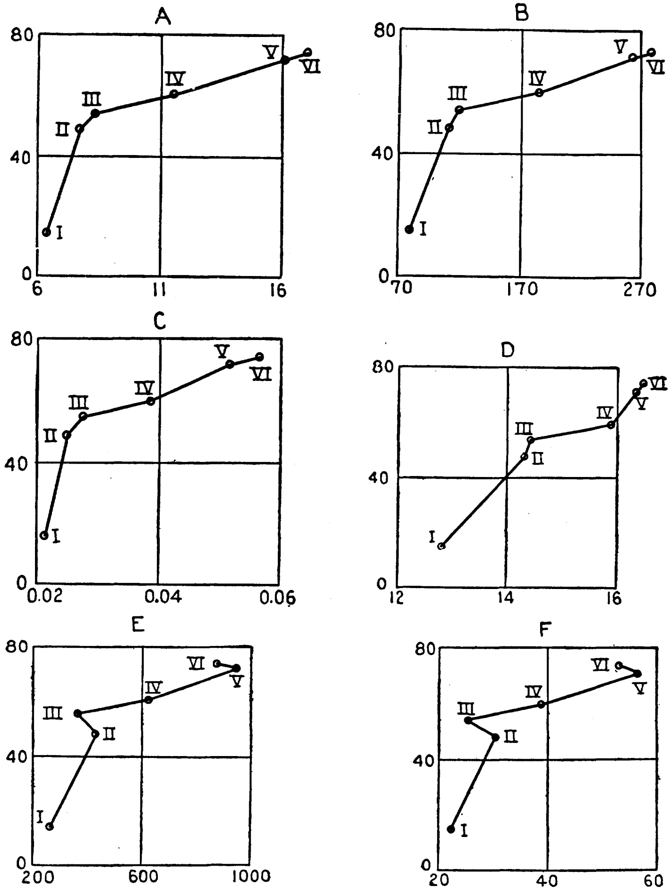

CHART IV. (Semi-indirect Reflectors Differing in Density.) Showing the tendency of the six types of semi-indirect reflector to cause loss of power to sustain clear seeing. In Curve *A*, percentage drop in power to sustain clear seeing after work for the different reflectors is plotted against ratio of average brightness to brightness at point of work; in *B*, against ratio of lightest surface to brightness at point of work; in *C*, against average brightness; in *D*, against ratio of lightest surface to average brightness; in *E*, against ratio of lightest surface to darkest surface; and in *F*, against ratio of average brightness to darkest surface.

In the tables referred to on a previous page (footnote 1, p. 445), we have shown for the sake of completeness of representation the gradation of surface brightness in three ways: (1) Brightness measurements of prominent surfaces have been made. (2) Ratios have been given between surfaces of the first, second, third, etc., order of brilliancy, and surfaces of the lowest order of brilliancy; and between surfaces of the first, second and third order of brilliancy and the brightness at the point of work. And (3) the mean variation from the average and the percentage of mean variation have been shown. In the consideration of these specifications a number of single items might be selected as of possible significance in relation to the effect on the eye. Among these may be mentioned the order of magnitude of the highest brilliancies; the average brilliancy; the ratio of the highest to the lowest order of brilliancy; the ratio of the highest order of brilliancy to the brilliancy at the point of work (brightness of test-object and reading page); etc. In order to see which of these correlate most closely with the results of the test, curves have been constructed in which some of these features are plotted against the results of the test. These curves are given in Charts III. and IV. In Chart III., *B*, percentage loss of visual efficiency is plotted against the highest order of brilliancy, namely the brightness of the reflector. In Chart IV. are grouped the remainder of the curves.

3. *Translucent Direct Reflectors Differing in Density.*

In the fourth series of experiments it was decided to use the same reflectors as were used in the third with one omission (the blown Veluria) because of its close similarity to another in the series, and to instal them in accord with the principles of direct lighting. In this series was included also a set of reflectors of prismatic glassware, differing somewhat from the others in size and design. They will be designated by the numerals I., II., III., IV., V. and VI., numbered for convenience of treatment in the tables in the order of their effect on the eye from best to worst. Reflector I. is the pressed Druid; Reflector II. the blown glass toned brown (experimental); Reflector III. the blown white glass (experimental); Reflector IV.

the pressed Sudan; Reflector V. the pressed Sudan toned brown; and Reflector VI. the prismatic. The size and type of the first five of these reflectors have already been given. Reflector VI. is of the extensive type, 8¾ in. in diameter and 5¾ in. deep. Reflectors I.,

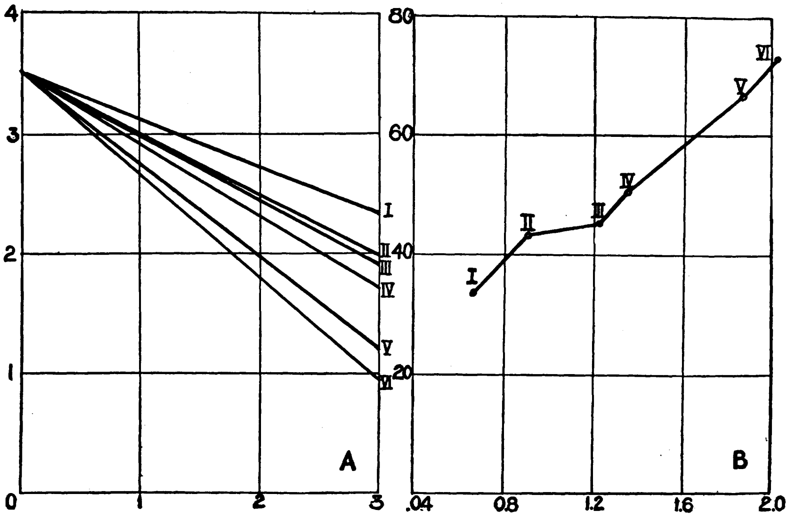

CHART V. (Translucent Direct Reflectors Differing in Density.) Showing the tendency of the six types of translucent direct reflectors to cause loss of power to sustain clear seeing. In *A*, power to sustain clear seeing before and after work is represented on the ordinate and hours of work on the abscissa; and in *B*, percentage drop in power to sustain clear seeing after work for the different reflectors is plotted along the ordinate and highest brightness of reflector in candlepower per square inch along the abscissa.

Reflector.	Volts.	Foot-candles.		45°.	Candle Power per Square Inch.
		Vertical.	Horizontal.		
Type I.	110	5.0	1.47	3.30	0.66
Type II	113	4.84	1.43	3.35	0.924
Type III	110	5.0	1.44	3.40	1.23
Type IV.	110.5	5.0	1.44	3.40	1.364
Type V	111	4.80	1.44	3.30	1.87
Type VI.	107	5.10	1.47	3.40	2.05

IV., V. and VI. are commercial products, but II. and III. are experimental products inserted in the series to give gradations in density. The blown Veluria used in the former series of experiments was omitted from this series because the illumination effects obtained and

the effects on the eye, as determined in preliminary experiments, differed so little from those gotten from the blown white glass as to be considered as of little significance for the present work. These reflectors were all used with 2¼ in. form "H" holders, and were installed on the ceiling pendant in accord with the principles of direct lighting. Full-frosted tungsten lamps were used as light sources with each installation. The results of this series of experiments are represented in Chart V.[2]

In the tables[3] referred to in footnote 1, p. 445, we have again

[2] In considering these results it should be borne in mind that these reflectors have been used to produce certain variations in illumination effects and that the work has not been conducted as a specific test of reflectors. For example, in order to secure in all cases approximately equal illumination at the test object, the lamps had to be operated at slightly higher voltages for some reflectors than for others. This produced for the different reflectors slightly different relative brightness values for outer surface and opening than would have been obtained had the lamps all been operated at the same voltage. Also clear and bowl-frosted lamps are more commonly used with these reflectors than full-frosted lamps. One effect of using clear or bowl-frosted lamps with them in this work would have been to have increased the brightness of both opening and outer surface of the reflectors and to have given, there is good reason to believe, a correspondingly uniformly poorer result for the eye. It is never entirely safe to predict results under conditions differing even slightly from what have been used, but from data at hand there is no reason to think that the change would have produced any significant difference in the relative rating of these reflectors. The full-frosted lamps were used for two reasons: (*a*) to test the whole group of reflectors under conditions as favorable as possible for the eye. This is admittedly only one point of view; the results might have had a more direct practical bearing had clear or bowl-frosted lamps been used. And (*b*), which is the chief reason, for the sake of making the work as far as possible comparable with the previous work, we desired to make the illumination of the test object as nearly equal as could be for the different reflectors, translucent and opaque, and equal to that used in the former work. This was best accomplished by the selection of lamps made.

[3] The following points might perhaps be cited in connection with the brightness specifications given in these tables. In case of the translucent reflectors, installed pendant, two important items of surface brightness should be taken into account, the brightness of the opening and the brightness of the outer surface of the reflector. If a dense reflector is chosen, for example, the brightness of the opening tends to become excessively high; also its apparent or physiologic brightness is increased by induction from its dark surroundings which effect does not register on the photometer. If, on the other hand, the reflector chosen transmits too much light the brightness of the outer surface of the reflector becomes too high for the comfort and welfare of the

shown the gradation of surface brightness in the manner described in the preceding section. And in order to ascertain which of the brightness specifications—order of magnitude of highest brilliancy, average brilliancy, ratio of highest to lowest order of brilliancy, ratio of highest order of brilliancy to average brilliancy, ratio of average to lowest brilliancy, ratio of highest order of brilliancy to brightness at point of work (brightness of test object and reading page), etc.—correlate most closely with the results for the tendency to cause loss of power to sustain clear seeing, curves have been constructed in which a number of these features were plotted against the results of the tests. These curves are given in Charts V. and VI. In Chart V., *B,* per cent. loss in power to sustain clear seeing is plotted against the highest order of brilliancy that varies by any considerable amount from installation to installation, namely, the brightness of the reflector—outer surface and opening. In Chart VI. are grouped the remainder of the curves.

Three points may be noted perhaps with reference to these charts: (1) The prismatic reflectors, which differ in design from the rest of the series, more or less conspicuously fall out of the curve in every case but two. The effect of difference in design on the smoothness of the curve comes out especially in the results with the opaque reflectors (shown in the report of the next series of tests), in which case there are marked differences in both size and design. All of the curves plotted on the above bases are very irregular in case of these reflectors with the exception of separate curves for three which are similar in design. For a statement of the probable reasons for this inequality see this paper, pp. 468–9. (2) The greater regularity of the curves is rather strikingly marked in which the highest order of brilliancy that varies by considerable amounts or the ratios in which

eye. For the translucent reflectors used in these tests, the best results have been obtained with the reflectors of medium density. The reverse of this was true, it will be remembered, when the same reflectors were installed inverted. The highest brightnesses when these reflectors are installed pendant are the filament spots on the lamps. Only very small areas of these spots are visible, however, and their brightness and the brightness of the lamp differ so little from installation to installation as to be, in all probability, of relatively little consequence in a comparative study of effects on the eye. The significant variables are thus the brightnesses of the outer surface and opening of the reflector.

this quantity appears, is plotted against the results of the test. This, it will be remembered, was true also of the work of the preceding

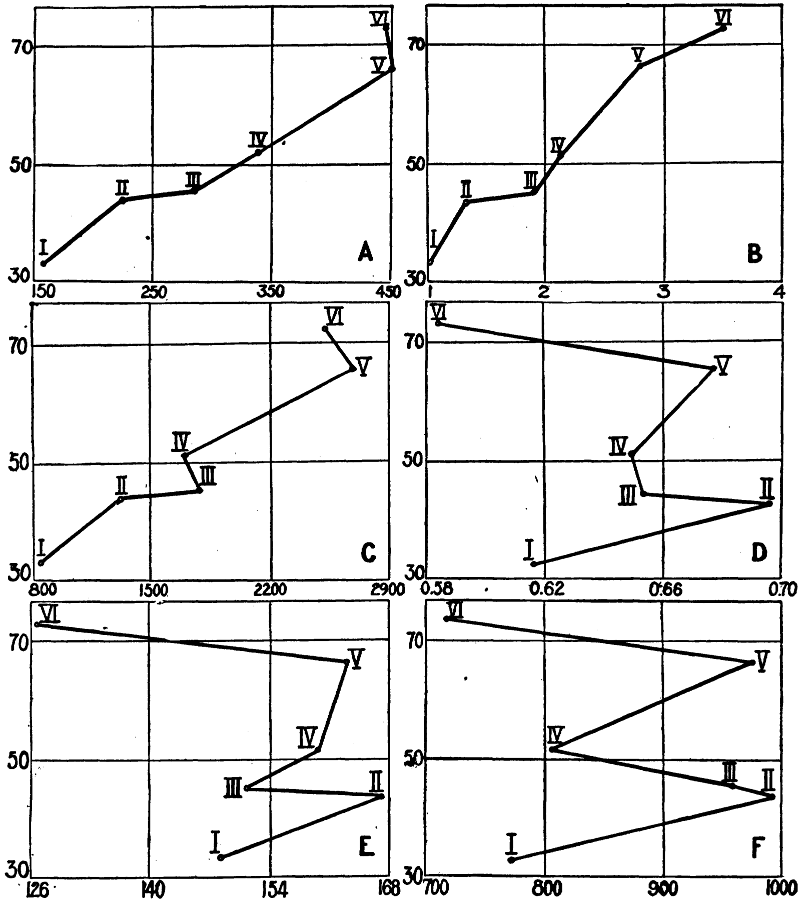

CHART VI. (Translucent Direct Reflectors Differing in Density.) Showing the tendency of the six types of translucent direct reflectors to cause loss of power to sustain clear seeing. In Curve *A,* percentage loss in power to sustain clear seeing after work is plotted against ratio of highest brightness of reflector to brightness at point of work; in *B,* against ratio of highest brightness of reflector to average brightness; in *C,* against ratio of highest brightness of reflector to darkest surface in field of view; in *D,* against average brightness; in *E,* against ratio of average brightness to brightness at point of work; and in *F,* against ratio of average brightness to darkest surface in the field of view.

experiments. (3) The range of brightness for this set of experiments is quite a little higher in the scale than for that of the former experiments with the same reflectors. This fact should be borne in mind, for example, in comparing the shape of the curves for the two sets of experiments in which highest order of brilliancy is plotted against the results of the tests. In case of the present experiments, for example, the curve begins at a point, 0.66 candle-power per square inch, which is well above the knee of the former curve. That is, the two curves are in general quite similar in shape when they are compared for the same range of brightness values. The former curve has, however, the greater regularity; but in connection with this fact it should be borne in mind that a variation of the brightness factor in separation can be more nearly accomplished with these reflectors when they are installed inverted than when they are installed pendant.

4. *Opaque Direct Reflectors Differing in Dimensions, Lining and Design.*

In this series of experiments the testing of pendant reflectors was continued. Seven totally opaque reflectors differing in lining, dimensions and design were used. In connection with the work of this series of reflectors, two points of perhaps more than usual interest may be noted: (*a*) By means of a modification of one of the reflectors used, Reflector IV., made to reduce the brilliancy of the opening, a field of view was given having the lowest maximum of brilliancy of any that we have as yet been able to obtain in an actual lighting situation; and (*b*) we were able to test more effectively than in any lighting situation previously used, the importance of evenness of surface brightness compared with evenness of illumination as a factor influencing the ability of the eye to maintain its power of clear and comfortable seeing.

The opaque reflectors represent a more promiscuous selection than the pendant translucent reflectors previously used. That is, in case of the translucent reflectors, all but one, Reflector VI., were of the same size and design, and the variations in the illumination effects were obtained by varying the density of the reflector alone;

while in case of the opaque reflectors the significant variations in the lighting effects were produced by changing the size (more especially the depth) of the reflector, the lining and the design. Of these Reflector IV. was of blown silvered glass with a system of spiral corrugations on its reflecting surface for the diffusion of light. This reflector was of the deep bowl type, 10½ in. in diameter and 11⅛ in. deep. Reflector V. was also of blown silvered glass and had a vertical system of finer corrugations than had Reflector IV. This reflector was 9⅜ in. in diameter and 8 in. deep and was more distributing in type than was Reflector IV. Both of these reflectors were used with 3¼ in. form "A" holders. Reflector VI. was a steel, aluminum-finished reflector of the intensive type, 8¼ in. in diameter and 7½ in. deep. This reflector was provided with a clip ring which was attached directly to the socket. Reflector VII. was a porcelain-enameled steel reflector of the shallow dome or distributing type, 15 in. in diameter and 6¼ in. deep. This reflector was used with a 2¼ in. form "O" holder.

Early in the work with these reflectors it was found that if good results for the eye were to be obtained with dense or completely opaque reflectors, some way must be gotten either of shielding the eye from the opening of the reflector or of reducing its brilliancy which increases as the density of the reflector is increased. Obviously something can be accomplished in this direction by using reflectors of the deep bowl type, giving specular rather than diffuse reflection, if the angle of presentation to the eye is not too great. Reflector IV., for example, is of this type. The opening of this reflector was of low brilliancy when viewed at an angle of 13° 19′, the angle of presentation to the eye for the two reflectors farthest from the observer in the present series of experiments. High up in the reflector, however, was a small but brilliant image of the lamp, a part of which was visible at an angle with the eye of 20° 17′, the angle made by the two reflectors at Outlet *B* (Fig. 1), and still more at an angle of 40°, the angle made by the two reflectors nearest the observer. It was thought advisable to find out how much this reflector could be improved in its effect on the eye by reducing the amount of reflection for a certain distance above the lower edge of the reflector. This was accomplished for the purpose of these ex-

periments by lining the reflector to a depth of 9.5 cm. (3.7 in.) with a mat surface of low reflection coefficient. This lining formed all of the surface that was visible in the openings of the four reflectors at Outlets *A* and *B*, and cut out the image of the lamp in the two reflectors at Outlet *B*. In the two reflectors nearest the observer, however, some of the bright lining and image were still visible, but the angle of presentation was here great enough that comparatively little effect on the comfort of the eye and its power to sustain clear seeing was had or was to be expected. Two sets of lining were used, one a very dark gray (reflection coefficient of about 4 per cent.); the other a lighter gray (reflection coefficient of about 38.5 per cent.). Reflector IV. provided with the first of these linings is designated in the charts as Reflector I., and with the second, as Reflector II. Still another modification was made of this reflector to lessen the effect of the opening on the eye. The apparent or physiologic brightness of this opening, as was the case with the other opaque reflectors, was enhanced by induction from the dark green coating or backing on the outer surface of the reflector. This effect is quite noticeable on inspection where a comparison with a reflector presenting less or no induction is afforded, but does not register in the photometer because the surroundings are not included in the photometric field. In case of Reflectors I. and II. this induction was lessened a great deal by covering the outside of the reflector with a closely fitting cap of mat white paper.

Because of the favorable results obtained with these modified reflectors, a similar modification of Reflector V, was made by the manufacturer for the purpose of reducing the brilliancy of its opening. In this case the band was made permanent by sand-blasting the corrugated glass surface of the reflector. The coefficient of reflection of the surface thus prepared was approximately 52 per cent. The band was made 5 cm. in width. While considerable improvement in the effect on the eye was produced by this modification, not nearly so good results were gotten as in the other case because (*a*) the coefficient of reflection was not sufficiently reduced by the sand blasting; and (*b*) Reflector V. was not deep enough to give the best results with this type of modification. The tip of the lamp, for example, was visible to the observer in case of four out of the six

reflectors in the field of view. This reflector is designated in the charts as Reflector III. All of the reflectors of this series were installed on the ceiling pendant in accord with the principles of direct lighting.

It was our wish to conduct this investigation, as has been the case in all of our work on the distribution factors, with the color value and the intensity of light as nearly equal as possible at the test object. Clear tungsten lamps were used with Reflectors I., II. and IV.; full-frosted lamps with Reflectors VI. and VII.; and bowl-frosted lamps with Reflectors III. and V. Clear lamps were used in the cases mentioned because in the first place in reflectors of this type the lamps were not visible to the observer at the point of work; and secondly, although the illumination given was high in the average, the distribution was such as to give a low illumination at the point of work. That is, the tendency of these reflectors, installed at the height used in our test room, was to give lanes of light directly beneath the two rows of reflectors, shading off to a correspondingly low value on either side. Full frosted lamps were used with Reflectors VI. and VII., because with Reflector VI. a part and with Reflector VII. all of the filament would otherwise have been visible to the observer; also the value of the illumination at the test object would have been much too high as compared with the other reflectors in the series and higher than the values used in previous work. In case of Reflectors III. and V. both of the above objects, namely, the better protection of the eye from the filament and the performance of the tests with the illumination values as nearly as possible equal to those obtained with the other reflectors and in previous work, was best accomplished by the use of bowl frosted lamps.

The results of this series of tests are represented in Chart VII. Again in order to ascertain which of the brightness specifications—order of magnitude of highest brilliancy; average brilliancy; ratio of highest to lowest order of brilliancy; ratio of highest order of brilliancy to average brilliancy; ratio of average to lowest brilliancy; ratio of highest order of brilliancy to brightness at point of work (brightness of test object and reading page); etc.—correlate most closely with the results for the tendency to cause loss of power to sustain clear seeing, charts were constructed in which a number of

these features were plotted against the results of the tests. As compared with the corresponding charts given for the previous experiments, these charts show great irregularity unless separate curves

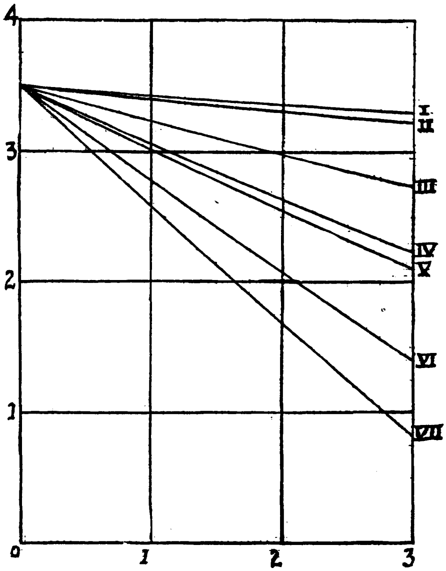

CHART VII. (Opaque Direct Reflectors Differing in Lining, Dimensions and Design.) Showing the tendency of the seven types of opaque direct reflectors to cause loss of power to sustain clear seeing. Loss of power to sustain clear seeing before and after work is represented on the ordinate and hours of work on the abscissa.

Reflector.	Volts.	Foot-candles.		45°.
		Vertical.	Horizontal.	
Type I.........	111	2.25	0.72	1.66
Type II........	111	2.90	0.90	1.95
Type III.......	107	4.25	1.19	2.95
Type IV.......	109	3.42	1.18	2.40
Type V........	107	4.30	1.21	3.00
Type VI.......	112	4.70	1.42	3.30
Type VII.......	109	4.90	1.47	3.30

are plotted for the reflectors similar in design. Reasons for the irregularity are, perhaps, (*a*) the method of specifying brightness. We are inclined to believe that if the surfaces of high brilliancy which vary considerably in extent for the series of reflectors se-

lected, were given in total candlepower instead of candlepower per square inch, they and the ratios based on them would correlate more closely with the effects on the eye. That is, it is a well known law in physiological optics that an increase in the area of a bright surface functions to a certain extent as an increase in its brightness. The opening of Reflector VII., for example, which gives the poorest results for the eye, has a lower intrinsic brightness than has the opening of Reflector VI.; but a great deal more of it is visible to the observer, also a great deal more of the lamp. When the surfaces in question differ in area to any very great extent, it is obvious that a measurement in candlepower per square inch is not an adequate specification when effects on the eye are to be considered. The total value in candlepower would be much more representative of the comparative power of these surfaces to affect the eye. (*b*) The angle of presentation to the eye. The openings of the different types of reflector differed in their distances above the working plane, although installed on the ceiling in every case. And (*c*) the number of factors varied. Brightness is not the only one of the distribution factors varied by considerable amounts by the different types of reflector. Because of the irregularities shown by these curves, space has not been taken to represent them here.

For all the conditions represented in this and preceding sections the work of testing was completed by determining for the different types of reflectors the relative tendencies to produce ocular discomfort as was noted in our introductory chapter. Two cases were made of this determination—one with the eye at rest, maintaining no particular adjustment, and the other when it was at work. Space has not been taken here for a statement of the results of these determinations. They are given in tabular form,[4] with a comparison in per cent. of the mean error of the determination and the change produced by changing the conditions tested, in the references appended below. In these tables are included also for the sake of comparison results expressing the tendency of each type of reflector to cause loss of ability to sustain clear seeing. A high correlation was

[4] *Transactions of the Illuminating Engineering Society,* 1915, X., pp. 497–500; 1915, X., pp. 1114–1116; 1916, XI., pp. 1129–1131; 1917, XII., pp. 477–479.

found to obtain in each case between the tendency to produce ocular discomfort and to cause loss in power to sustain clear seeing.

As was stated earlier in the paper a marked characteristic of the effects produced by the dense and completely opaque direct reflectors was the low illumination of the ceiling and the upper part of the room, and the high and in some cases almost glaring illumination of the floor and objects in the working plane. So far as effects on the eye of the kind registered by our tests are concerned, however, these irregularities of illumination and of the low surface brightnesses extraneous to the lamp and reflector seem to be of comparatively little consequence so long as the higher brilliancies of lamp and reflector are themselves taken care of. In this series of experiments, including the translucent direct reflectors, we have had quite wide variations in the distribution of illumination, ranging from well-illuminated ceilings and comparatively evenly illuminated walls and working plane for the direct reflectors of medium density to the dark ceilings and upper parts of the room and highly illuminated lower half in case of the opaque reflectors. And considering this work in connection with the preceding work, by means of the opaque and translucent reflectors turned both up and down, and reflectors of the distributing and focusing types, we have had the greatest amount of light first in the upper half of the room, then in the lower half, and within limits lanes of light have been produced; still it has been possible to get in all of these cases comparatively good effects on the eye so long as no excessive brilliancies were introduced into the field of view. Table I., for example, has been prepared to show the difference in the evenness of the illumination on the working plane for Reflector I. of the series of translucent direct reflectors (designated in the table as Reflector *A*) and Reflectors II. and IV. of the present series of opaque reflectors; and Chart VIII., Fig. 1, to give a graphic representation of the eye's ability to sustain clear seeing for these reflectors and Reflector I. of the present series. (The distribution of illumination for Reflector I. was so similar to that for Reflector II. that it has been omitted from Table I.). A comparison of this table and chart shows the following points. Reflector *A* gives a comparatively even illumination not only of the working plane but of the entire room, and Reflectors I. and II. a very

TABLE I.

SHOWING A COMPARISON OF THE EVENNESS OF ILLUMINATION FOR REFLECTOR *A* (I. OF THE TRANSLUCENT DIRECT SERIES) AND I. AND II. OF THE OPAQUE DIRECT SERIES.

Reflector *A* gives a comparatively even illumination and Reflector II. a very uneven illumination; yet Reflector II., from which all high brilliancies have been eliminated, gives much better results for the eye, so far as tendency to produce discomfort and power to sustain clear seeing are concerned, than Reflector *A*. Furthermore, Reflector IV., which gives the same general type of distribution of illumination as Reflector II., but has not had the brilliancy of its opening cut down, gives poorer results for the eye than Reflector *A*. Reflector II., it will be remembered, is Reflector IV. modified so as to reduce the brilliancy of its opening. In this table, the results are arranged just as the stations occur in the test room. (See Fig. 1, Plan of Test Room.) Space has been taken here for a comparison only of the vertical components of illumination for the three reflectors.

Reflector Type *A*.								Reflector Type II.								Reflector Type IV.							
	1.40								0.58								0.58						
	3.1	3.5	3.1	3.0	3.4	3.0			5.7	6.6	1.93	1.31	4.35	3.2			2.8	5.0	2.3	1.73	6.2	4.0	
	4.3	5.2	4.7	4.3	4.9	3.8			7.8	6.5	3.7	3.0	10.8	6.4			7.6	5.85	5.08	4.1	9.1	7.8	
	4.7	5.5	4.9	4.6	5.4	4.5			5.4	7.1	2.8	2.85	10.0	7.1			5.8	8.8	4.65	3.68	10.8	8.4	
2.3	4.7	5.5	5.38	5.0	5.5	4.8		1.25	6.8	5.6	3.9	3.7	5.6	6.7		1.23	6.4	5.2	5.8	5.5	5.9	8.1	
2.65	4.7	5.8	5.2	5.2	6.0	5.0		1.17	6.0	8.8	4.2	3.2	8.7	6.6		1.23	5.36	9.5	4.6	3.9	11.2	6.8	
3.2	5.1	6.1	5.4	5.3	5.9	4.85		1.16	5.8	5.1	5.3	3.75	5.8	6.95		1.54	7.1	5.2	5.4	4.3	8.2	7.8	
2.8	5.1	6.0	5.4	5.1	5.6	4.75	3.3	1.12	5.8	9.5	3.9	3.0	8.8	4.2	1.4	1.48	5.8	10.8	4.3	4.8	13.2	6.5	2.12
2.38	4.25	5.2	4.4	4.1	4.60	3.7	2.55	1.37	7.4	5.3	5.9	3.5	7.2	6.4	1.25	1.7	7.6	4.6	5.82	6.65	5.2	9.6	2.15
1.96	3.2	3.5	3.0	3.2	3.2	2.75		0.99	4.8	7.8	3.25	2.12	5.8	3.12		1.04	4.0	7.0	2.8	3.1	8.9	4.6	
1.68	1.75	1.5						0.56	0.92	1.18						0.51	1.01	1.27					

uneven illumination; yet Reflectors I. and II., from which all high brilliancies have been eliminated, give very much better results for the eye than Reflector *A* so far as the power to sustain clear and comfortable seeing is concerned; and Reflector IV., which gives the same general type of distribution of illumination as Reflectors I. and II. but has not had the brilliancy of its opening cut down, gives

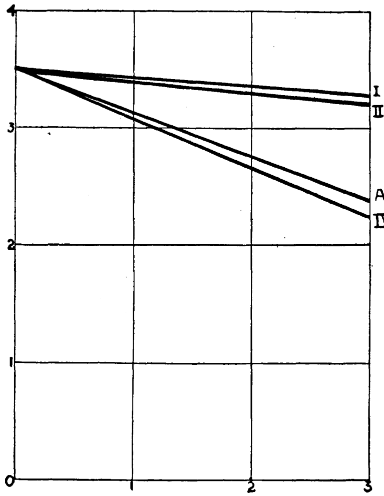

CHART VIII.

FIG. 1. Showing a comparison of the effects of unevenness of illumination and unevenness of surface brightness on the power of the eye to sustain clear seeing for a period of work. Reflectors I., II. and IV. give a very uneven illumination (dark upper walls and ceiling and lanes of light in the working plane); but the brightness of the openings of Reflectors I. and II. have been reduced by lining Reflector IV. to a depth of 9.5 cm. with surfaces of low reflection coefficient, 4 per cent. and 38.5 per cent. respectively. *A* is a translucent reflector giving a comparatively even illumination of walls, ceiling and working plane. All are installed pendant in accord with the principles of direct lighting.

poorer results for the eye than Reflector *A*. The results for Reflectors I., II. and IV. were taken from a series in which an attempt was made to find the maximum brightness of opening which the eye could stand without much loss in power to sustain clear and comfortable seeing with the types of reflector and installation used. The effect on the eye of Reflector I. (coefficient of reflection of

lower edge, 4 per cent.) differs very little, it will be observed, from that of Reflector II. (coefficient of reflection of lower edge, 38.5 per cent.). Any increase of the value of this coefficient above 38.5 per cent., however, caused a much more rapid change in result.

It may be of interest to append at this point another chart, Chart VIII., Fig. 2. In this chart are represented the best results we have as yet been able to obtain with the different types of translucent and

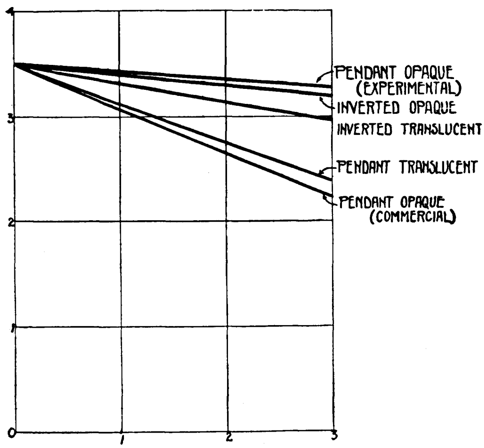

FIG. 2. Showing a comparison of the best effects we have been able to obtain with different types of lighting. The installations which have caused the least loss in power to sustain clear seeing are the ones which give the lowest maximum brilliancy in the field of view.

opaque reflectors installed pendant and inverted. From this chart it will be seen that comparatively good results may be gotten with both pendant and inverted reflectors. In general, however, the work has shown that the problem of protecting the eye from excessive brilliancies and of producing at the same time a satisfactory evenness of illumination presents greater difficulty in case of the pendant than in case of the inverted reflectors and has apparently been less adequately dealt with thus far in the work of reflector designing.

III. Other Investigations Pertaining to the Hygienic Employment of the Eye.

These include the effect of different types of eye-shades under different conditions of lighting; the effect of different conditions of

lighting on the extrinsic muscles of the eye; the effect of the angle at which the light falls on the work; the effect of motion pictures; etc. Space can not be taken in this paper for a detailed report of these investigations. For convenience of reference a complete bibliography of the studies published up to the present time is appended at the end of the paper.

IV. Ocular Discomfort in Relation to the Position of the Source of Light in the Field of View.

In addition to studying the conditions that give us maximal visual efficiency or power to sustain clear seeing, it is important also to determine the lighting conditions and eye factors that cause ocular discomfort. Therefore, in case of each of the lighting situations tested for tendency to cause loss in power to sustain clear seeing, we have determined the tendency to produce ocular discomfort, as has been noted in the preceding pages. In the work on the lighting systems previously described, however, the effect of the angle of presentation of surfaces of high brilliancy (lamp, surfaces and openings of reflector, ceiling spots, etc.) on both the power to sustain clear seeing and the tendency to produce ocular discomfort was shown through a comparatively small range of variation of angle. It was thought advisable to supplement this work by determining the effect on the tendency to produce ocular discomfort for a wider range of variation of angle of presentation. For this purpose a large perimeter was used, along the arm of which the brilliant surface, the effect of which was to be determined, could be moved. A variable area of brilliant surface was obtained by mounting on the arm of the perimeter a lamp house in the side of which next to the observer's eye a large iris diaphragm was inserted. The brilliancy and color value of this test surface could be varied within limits to suit the needs of the experiment by means of absorption screens and filters. Larger variations of intensity were obtained by means of the use of lamps of different wattages. The arm of the perimeter could be shifted to any meridian in which it was desired to work and the lamp could be moved at will along the arm. Working in this way it is possible to investigate the effects of many types of distribution

of surface brilliancy in the field of view and many variations of intensity and color value. Of these variations the results of only one will be given here, namely, the exposure of the brilliant surface at different points in the field of view for one eye when fixation and accommodation were taken for a point at a distance of one meter.

In carrying out the investigation the following precautions were observed. (*a*) It was found better to work in a room moderately illuminated by a source of light behind the observer and entirely concealed from him, rather than in the dark room. The intervals of dark adaptation between exposures in the dark room seemed to make the observer's eye too sensitive for our purpose. This was especially true for certain parts of the periphery of the field of view. In becoming supersensitive there was a tendency to become erratically sensitive. (*b*) It was found that blinking serves as a variable factor for the relief of discomfort and that the amount of blinking must be made constant from test to test. This was accomplished by having the observer blink at equal intervals during the exposure, timing himself by the stroke of a metronome. The interval most natural and suitable for this purpose was determined for each observer separately. (*c*) All comparisons were planned in series. For example, if it were desired to compare the sensitivity for the temporal and nasal halves of the field of view in a given meridian, the exposure was made first at one point in one half and next at the corresponding point in the other half and the order of giving them was changed. This was to guarantee that the eye should be as nearly in the same condition with regard to progressive fatigue, etc., as was possible. Further to safeguard against error in this regard, series were compared in which the exposures were repeated in the reverse order. (*d*) An interval of recovery was allowed between exposures. This interval had to be determined separately for each observer and often had to be made different for the same observer on different days. It was never changed, however, during the course of a series, the results of which were to be compared. (*e*) In order that the observer's head be held rigidly in position during the exposure, he was required to bite an impression of his teeth previously made and hardened in wax on a mouthboard. (*f*) As has been the case in all of this work, care has been exercised in the choice of observers to

select only those who had already shown a satisfactory degree of precision in other work in physiological optics and whose clinic record showed no uncorrected defects of consequence. All were under thirty years of age. Before being allowed to take part in the actual work the results of which were used in the comparative study, each observer was trained to a satisfactory degree of precision in a preliminary series of tests with the light exposed at several points in the field of view. In the actual work of testing the results were compiled from a number of observations and the precision was checked up by the size of the mean variation. No results were accepted as significant unless the variation produced by changing the position of the source in the field of view was largely in excess of the mean variation or mean error for each position tested. When an exposure was to be made, the fixation was taken, the light turned on and a record was made by the observer on a kymograph of the time that was required for just noticeable discomfort to be set up; or, if it were desired, when the different stages of discomfort were reached. The judgment was found to present no special difficulty and the method, when properly applied, to provide a feasible means for comparing the sensitivity of the eye to discomfort under all the conditions to which we have been able thus far to extend its application. In actual practice the method also brings out an analysis of ocular discomfort.

Ocular discomfort seems to be a complex of three experiences each of which develops at a different time. When the light is turned on, we have at once glare. This is a light sensation and though unpleasant has no painful elements. Next comes a conjunctival sensation which begins with what is commonly called "sandiness" and soon passed over into a sharp, stinging, stabbing pain. Lastly there is what is probably a muscular discomfort, a hurting and aching in the ball of the eye which, if the exposure is continued long enough, seems to radiate to the socket and the surrounding regions of the face and head, the arch of the brow, the forehead, the temples, etc.

The comparative determinations were made in 12 meridians of the field of view from the center to the limit of vision in the given meridian at points separated by 15 degrees. Space will be taken here only for a general statement of result. In general for all of our ob-

servers, with the exception of two meridians for one observer, the point of maximal sensitivity to discomfort was out of the center of the retina; the nasal half of the retina was more sensitive than the temporal half and the upper half more sensitive than the lower. In passing from the center to the periphery of the retina, the sensitivity is found first to increase and then to decrease, becoming extremely little at the limits of the field of vision. In the horizontal meridians both on the temporal and nasal sides, maximal sensitivity is found around and in the region included between 15°–45°; in the vertical meridians, around and in the region included between 15° and 30°.

V. The Effect of Different Illuminants on the Power of the Eye to Sustain Clear and Comfortable Seeing.

In the work as conducted up to the present time a study has been made of the effect on the eye of differences in the way in which the light is delivered to it from a given type of illuminant. In work now in progress, a series of similar studies is being made of the illuminant itself. Different illuminants are being used with the same conditions of installation, shading, etc., and a correlation is being made between the lighting effects obtained and the power to sustain clear and comfortable seeing. As the tests are being conducted, color value is the only variable present of any magnitude from illuminant to illuminant. The tests so far as completed show that color value, while not exercising so important an influence as improper and inadequate shading on the power of the eye to sustain clear and comfortable seeing in lighting conditions as we have them in current practice, is a factor that should not be ignored in the work that is being done in the interests of the conservation of vision.

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April, 1917.